CLAIMS

1. An electrodeionization apparatus comprising:

at least one ion-depletion compartment;

a first layer of a first ion exchange material positioned in the at least one ion-depletion compartment;

a second layer of a second ion exchange material positioned adjacent and downstream of the first layer; and

a third layer comprising anion and cation exchange material positioned adjacent to and downstream of the second layer.

2. The electrodeionization apparatus of claim 1 wherein the first layer comprises cation exchange resin and the second layer comprises anion exchange resin.

3. The electrodeionization apparatus of claim 1 wherein the first layer comprises anion exchange resin and the second layer comprises cation exchange resin.

4. The electrodeionization apparatus of claim 1 wherein the first or second layer comprises cation exchange material and a dopant.

5. The electrodeionization apparatus of claim 4 wherein the dopant comprises anion exchange resin.

6. The electrodeionization apparatus of claim 1 wherein the anion exchange material is a specialized electroactive media comprising Type I and Type II anion exchange resin.

7. The electrodeionization apparatus of claim 1 wherein the first or second layer comprises anion exchange material and a dopant.

8. The electrodeionization apparatus of claim 7 wherein the dopant is cation exchange material or electrically active non-ion exchange material.

9. The electrodeionization apparatus of claim 1 wherein a volume of the second layer is greater than a volume of the first layer.

10. The electrodeionization apparatus of claim 7 wherein the volume of the second layer is about three times the volume of the first layer.

11. An electrodeionization apparatus comprising:

at least one ion depletion compartment;

a first layer of ion exchange material disposed in the ion depletion compartment and comprising cation exchange resin or anion exchange resin;

a second layer of ion exchange material disposed in the ion depletion compartment and comprising cation exchange resin or anion exchange resin and being different than the first layer, wherein at least one of the layers further comprises a dopant.

12. The electrodeionization apparatus of claim 11 wherein the first layer comprises cation exchange resin and the second layer comprises anion exchange resin.

13. The electrodeionization apparatus of claim 11 wherein the first layer comprises anion exchange resin and the second layer comprises cation exchange resin.

14. The electrodeionization apparatus of claim 11 wherein the first or second layer comprises cation exchange material and a dopant.

15. The electrodeionization apparatus of claim 14 wherein the dopant comprises anion exchange resin.

16. The electrodeionization apparatus of claim 5 wherein the anion exchange resin is a specialized electroactive media comprising Type I and Type II anion exchange resin.

17. The electrodeionization apparatus of claim 1 wherein the first or second layer comprises anion exchange material and a dopant.

18. The electrodeionization apparatus of claim 17 wherein the dopant is cation exchange material or electrically active non-ion exchange material.

19. The electrodeionization apparatus of claim 1 wherein a volume of the second layer is greater than a volume of the first layer.

20. The electrodeionization apparatus of claim 7 wherein the volume of the second layer is about three times the volume of the first layer.

21. An electrodeionization apparatus comprising:

a first cell comprising anion or cation exchange material;

a second cell in fluid communication with the first cell, the second cell comprising anion or cation exchange material and being different than the exchange material of the first cell; and

a third cell in fluid communication with the second cell, the third cell comprising a mixed ion exchange material.

22. The electrodeionization apparatus of claim 21 wherein the first and second cells are in a common module.

23. The electrodeionization apparatus of claim 22 wherein the third cell is in the common module.

24. The electrodeionization apparatus of claim 21 wherein the second cell is of greater thickness than the first.

25. The electrodeionization apparatus of claim 24 wherein the second cell is greater than about two times the thickness of the first cell.

26. The electrodeionization apparatus of claim 25 wherein the thickness of the second cell is greater than about three times the thickness of the first cell.

27. The electrodeionization apparatus of claim 24 wherein the first cell comprises cation exchange resin.

28. The electrodeionization apparatus of claim 27 wherein the second cell comprises anion exchange resin.

29. The electrodeionization apparatus of claim 21 wherein a current applied to the first cell is independently controllable from a current applied to the second cell.

30. The electrodeionization apparatus of claim 29 wherein a current applied to the third cell is independently controllable from that applied to the first or second cell.

31. The electrodeionization apparatus of claim 21 further comprising a fourth cell positioned downstream of the second cell and upstream of the third cell.

32. The electrodeionization apparatus of claim 31 wherein the fourth cell comprises substantially the same ion exchange material as the second cell.

33. The electrodeionization apparatus of claim 32 wherein the second and fourth cells are in the same module.

34. The electrodeionization apparatus of claim 32 further comprising a fifth cell positioned downstream of the fourth cell and upstream of the third cell.

35. A method of purifying water comprising:

applying an electric field to an electrodeionization apparatus, the electrodeionization apparatus comprising a cation exchange layer, an anion exchange layer and a mixed ion exchange layer;

passing a first fluid through the cation exchange layer to produce a second fluid;

adjusting the pH of the second fluid by passing the second fluid through the anion exchange layer to produce a third fluid; and

passing the third fluid through the mixed ion exchange layer.

36. The method of claim 35 wherein the step of passing the second fluid through the anion exchange layer raises the pH by at least about 2 pH units.

37. The method of claim 35 wherein the pH of the second fluid is below 7.

38. The method of claim 37 wherein the pH of the second fluid is below about 6.

39. The method of claim 35 wherein a contact time with the cation exchange layer is less than a contact time with the anion exchange layer.

40. The method of claim 39 wherein the contact time with the anion exchange layer is more than about twice the contact time with the cation exchange layer.

41. The method of claim 40 wherein the contact time with the anion exchange layer is about three times the contact time with the cation exchange layer.

42. The method of claim 14 wherein the first fluid contains a first concentration of a weakly ionizable species and the third fluid contains the weakly ionizable species at a concentration that is less than about 10% of the first concentration.

43. The method of claim 21 wherein the concentration in the third fluid is less than about 5% of the first concentration.

44. The method of claim 43 wherein the concentration in the third fluid is less than about 1% of the first concentration.

45. The method of claim 42 wherein the weakly ionizable species is silica and the concentration in the third fluid is less than 1 ppb.

46. The method of claim 42 wherein the weakly ionizable species is boron and the concentration in the third fluid is less than 1 ppb.

47. The method of claim 35 wherein the cation or anion exchange layer comprises a dopant.

48. A method of purifying water comprising:

applying an electric field to an electrodeionization apparatus, the electrodeionization apparatus comprising two layers, wherein the two layers are an anion exchange layer and a cation exchange layer wherein at least one of the layers comprises a dopant;

passing a first fluid through one of the two layers to produce a second fluid; and

passing the second fluid through the other of the two layers, to produce a third fluid wherein the third fluid is at a pH that is at least about one pH unit adjusted from the pH of the first fluid.

49. The method of claim 48 further comprising passing the third fluid through a mixed ion exchange layer under the influence of an electric field.

50. The method of claim 49 wherein the feed water comprises a weakly ionizable species at a first concentration and the third fluid comprises the weakly ionizable species at a concentration that is less than about 10% of the first concentration.

51. The method of claim 50 wherein the concentration of the third fluid is less than about 5% of the first concentration.

52. The method of claim 51 wherein the concentration of the third fluid is less than about 1% of the first concentration.

53. The method of claim 50 wherein the weakly ionizable species is selected from the group consisting of silica compounds, boron compounds and carbon compounds.

54. The method of claim 50 wherein in the weakly ionizable species is a cationic species.

55. The method of claim 54 wherein the cationic species is ammonia.

56. The method of claim 48 wherein a pH of the second fluid is at least about 1 pH unit higher than a pH of the first fluid.

57. The method of claim 56 wherein the pH of the second fluid is at least about 2 pH units higher than the pH of the first fluid.

58. The method of claim 48 wherein the pH of the third fluid is at least about 1 pH unit lower than the pH of the second fluid.

59. A water purification apparatus comprising:

a first reverse osmosis device;

an electrodeionization apparatus in fluid communication with the first reverse osmosis device;

an anion exchange layer disposed in the electrodeionization apparatus;

a second reverse osmosis device in fluid communication with the electrodeionization apparatus, the second reverse osmosis device in communication with the first reverse osmosis device via the electrodeionization apparatus; and

a bypass loop providing fluid communication between the first reverse osmosis device and the second reverse osmosis device.

60. The apparatus of claim 36 further comprising a cation exchange layer positioned between the first reverse osmosis device and the anion exchange layer.

61. A method of purifying water comprising:

passing water through a first reverse osmosis device to produce a first fluid;

raising the pH of the first fluid, without adding an alkaline substance, to produce a second fluid; and

passing the second fluid through a second reverse osmosis device.

62. The method of claim 61 wherein the pH of the first fluid is raised by passing the fluid through an electrodeionization apparatus comprising an anion exchange layer.

63. The method of claim 62 further comprising a step of transferring a portion of the first fluid to the second reverse osmosis device without transferring the portion through the electrodeionization device.

64. A water purification apparatus comprising:

a first electrodeionization cell comprising ion exchange material;

a second electrodeionization cell comprising ion exchange material;

a first reverse osmosis device in fluid communication with the first electrodeionization cell and the second electrodeionization cell; and

a second reverse osmosis device in fluid communication with the second electrodeionization cell.

65. The apparatus of claim 64 wherein the first and second electrodeionization cells are in a common electrodeionization module.

66. The apparatus of claim 65 wherein at least one layer comprises a dopant.

67. A method of purifying fluid comprising:

passing a feed fluid through a first electrodeionization cell to adjust pH to produce a first fluid;

passing the first fluid through a first reverse osmosis device to produce a second fluid;

passing the second fluid through a second electrodeionization cell to adjust pH to produce a third fluid; and

passing the third fluid through a second reverse osmosis device to produce a purified fluid.

68. The method of claim 67 wherein the first electrodeionization cell and the second electrodeionization cell are in the same electrodeionization device.

69. The method of claim 67 wherein the pH is first lowered and then raised.

70. The method of claim 67 wherein the pH is first raised and then lowered.

71. The method of claim 67 wherein the pH is raised by passing fluid through an electrodeionization cell comprising a majority of anion resin.

72. The method of claim 67 wherein the pH is lowered by passing the fluid through an electrodeionization cell comprising a majority of cation resin.

73. The method of claim 71 wherein the fluid passes through an electrodeionization cell comprising a layer of cation resin followed by a layer of anion resin.

74. The method of claim 67 wherein the purified fluid contains weakly ionizable cations and weakly ionizable anions at concentrations that are below the concentrations of the same cations and anions in the feed fluid.

75. The method of claim 74 wherein the concentrations in the purified fluid are less than 1% of the concentration in the feed fluid.

76. An electrodeionization cell wherein a rate of removal of a weakly ionizable species is substantially constant throughout a length of the cell.

77. The apparatus of claim 76 wherein a pH of a fluid in the cell is greater than or equal to about 8.

78. The apparatus of claim 77 wherein the pH is greater than or equal to about 9.

79. The apparatus of claim 76 wherein a pH of a fluid in the cell is less than or equal to about 6.

80. The apparatus of claim 79 wherein the pH is less than or equal to about 5.

81. An electrodeionization device comprising:

a first ion exchange layer comprising mixed ion exchange material;

a second ion exchange layer comprising anion exchange material, the second layer in fluid communication with the first layer; and

a third ion exchange layer comprising cation exchange material, the third layer in fluid communication with the second layer.

82. The electrodeionization device of claim 81 wherein the first, second and third ion exchange layers are in a common cell.

83. The electrodeionization device of claim 81 wherein each of the ion exchange materials is an ion exchange resin.

84. The electrodeionization device of claim 81 wherein the second ion exchange layer is adjacent the first ion exchange layer.

85. The electrodeionization device of claim 81 wherein the third ion exchange layer is adjacent the second ion exchange layer.

86. The electrodeionization device of claim 81 wherein the first ion exchange layer comprises doped cation exchange material.

87. The electrodeionization device of claim 86 wherein each of the first, second and third layers are in a common cell.

88. The electrodeionization device of claim 86 wherein each of the ion exchange materials is an ion exchange resin.

89. The electrodeionization device of claim 86 wherein the first ion exchange layer is doped with anion exchange resin.

90. The electrodeionization device of claim 89 wherein the anion exchange resin comprises type I and type II anion exchange resin.

91. The electrodeionization device of claim 89 wherein the first ion exchange layer is doped with the ion exchange material comprising the second ion exchange layer.

92. The electrodeionization device of claim 89 wherein the first ion exchange layer is doped with less than about 40% dopant material.

93. A method comprising:

passing feed water sequentially through three layers, a first layer comprising anion and cation exchange resin, a second layer comprising anion exchange resin, and a third layer comprising cation exchange resin.

94. The method of claim 93 wherein the feed water is pre-treated by reverse osmosis.